LUBRICATION

A Technical Publication Devoted to the Selection and Use of Lubricants

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Improvements in Petroleum Products Over Recent Years

PETROLEUM became associated with power and machinery operation some fifteen years before the Drake well. In fact, the use of mineral oil as a lubricant was tried out in the textile industry as early as 1845. To be true, the oily material was obtained with salt water from a salt well at Tarentum, Pennsylvania, but it was petroleum and after experimentation it was combined with sperm oil to form a very excellent lubricant for the type of cotton mill spindles in use at that time.

From this early record of research with petroleum, a most interesting program of scientific investigation has developed. The past several years in particular have witnessed a remarkable coordination of refinery procedure with laboratory research, and the standardization of production methods. Simultaneously our industry recognized the value of cooperating with other industries in the study of their fuel and lubricating problems. Obviously, the automotive, Diesel and aviation fields have excited the most spectacular activity. This led to the perfection of the anti-knock engine, the chassis dynamometer, and most recently a program of low-temperature research which will be of inestimable value to the motorist in solving the problem of cold starting.

AUTOMOTIVE FUEL RESEARCH

Study of petroleum fuels was accelerated by the perfection of the automotive, aviation and Diesel engines. Heavier fuels and gasolines had naturally been among our principal products for years, but with the spanning of the Atlantic and the development of the high-compression automotive engine, the research of the petroleum industry was of necessity directed most actively toward motor car and aviation fuels and lubricants. This led to development of octane ratings of gasolines and the appreciation of heat-absorbing characteristics of motor oils. Four major problems of petroleum research were involved, viz.:

Improvement in volatility and reduction of vapor-lock.
Improvement of anti-knock characteristics.
Making cold starting easier.
Stability.

So the history of gasoline is intimately allied with the history of the automotive engine. Prior to 1910, gasoline was a waste by-product obtained during the refinement of crude oil. Kerosine was the most important light product derived from petroleum. But with the expansion of motor transportation, gasoline came into its own as the essential fuel for operation of the engine.

In those days when the demand for gasoline was limited and but little difficulty was experienced with engines, which could be attributed to the fuel, no particular attention was paid to specifications for the latter. The only qualification, as denoted by the first government specification issued by the Navy, was that the gasoline should be free from kerosine or lubricating oil. Volatility was not taken

into serious consideration. Today, however, it has been definitely proved that fuel volatility is related to power. In other words, engine design leans toward improved operation and increased economy, so gasoline of high volatility is required in order to increase the power output.

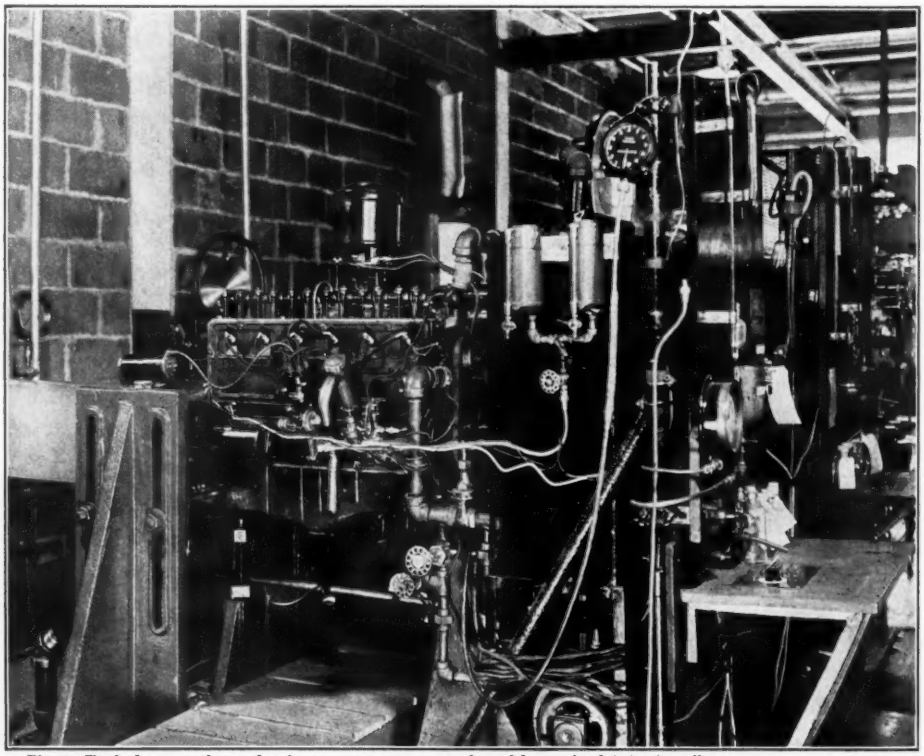


Fig. 1—Typical automotive engine-dynamometer set-up as adapted for testing lubricating oils.

Vapor-Lock Prevention

Vapor-locking became a serious objection with certain types of cars shortly after the improvement of engine design which required increased volatility of the fuel. By vapor-lock we mean any interruption in the normal operation of an automotive engine, which is caused by gasoline vapor forming in the fuel supply system due to the gasoline becoming overheated. Vapor-locking is very disturbing to the motorist, especially in warm weather or when he is compelled to idle for any length of time in congested traffic. When it occurs, the engine may stall, and until the accumulated fuel vapors in the carburetor are dissipated, it will be difficult to start the engine again.

Laboratory research developed that the vapor-locking tendency of a gasoline is a function of the vapor pressure and the front end of the distillation curve; furthermore, that it may be accelerated by high temperatures in the fuel supply system. The petroleum industry has assisted in solving this problem by controlling the vaporization tendency of the fuel at the temperature in the fuel line; the automotive engine builder by providing for a cooler fuel system.

It was necessary to further intensify the laboratory research of the petroleum industry when detonation or knock became an objection in the operation of the high compression engine. The automotive engineer was fully aware that knocking could be avoided by certain mechanical provisions such as retarding the spark, enriching the fuel mixture or lowering the compression ratio. All, however, led to reduced power; still the compression ratio was being constantly increased to get more power.

So the petroleum chemist had to work towards improving gasolines. He found that addition of materials which would serve as detonation retarders would solve the problem. Ultimately, tetra-ethyl lead was adopted from the maze of additive compounds which were studied. About the same time a joint committee of the petroleum and automotive industries known as the Cooperative Fuel Research Committee perfected an engine to measure the anti-knock characteristics of motor fuels. Hence the origin of the octane number.

Octane Number

This is a term which is still possessed of an elusive meaning to the average motorist and even to many who are familiar with chemical research in industry. It has been accepted oftentimes entirely too casually, so it will be interesting to investigate the meaning. It pertains to elimination of knock in the gasoline type of internal combustion engine, or that noisy effect which is so detrimental to power output.

When the scientists began to consider ways and means to reduce this occurrence when sudden or extreme loads were applied in the automotive type of engine, a type of test engine was necessary. In this engine the anti-knock value of a gasoline is noted by matching its knocking tendency against that of a reference fuel of known anti-knock characteristics. The design of this engine duplicates as closely as possible standard automotive practice. The conditions under which this engine is operated and method of procedure used are also representative. They have been approved by the American Society for Testing Materials; the procedure is called the A.S.T.M.-C.F.R. Method.

The primary reference fuels in the operation of the test procedure are hydrocarbons known as iso-octane with an arbitrary rating of 100 and normal heptane with an arbitrary rating of 0. By mixing the two a blend can be obtained with an anti-knock value equal to the fuel being tested. The resultant octane number is, therefore, the percentage of octane in this mixture of test fluids. In other words, it represents the relative proportion of iso-octane and normal heptane necessary to use in the test engine in order to get the same knocking characteristics as are obtained with the fuel being tested. Thus an octane number of "80" means that a mixture of 80 per cent. of iso-octane and 20 per cent. of normal heptane gives the same effect as the unknown fuel.

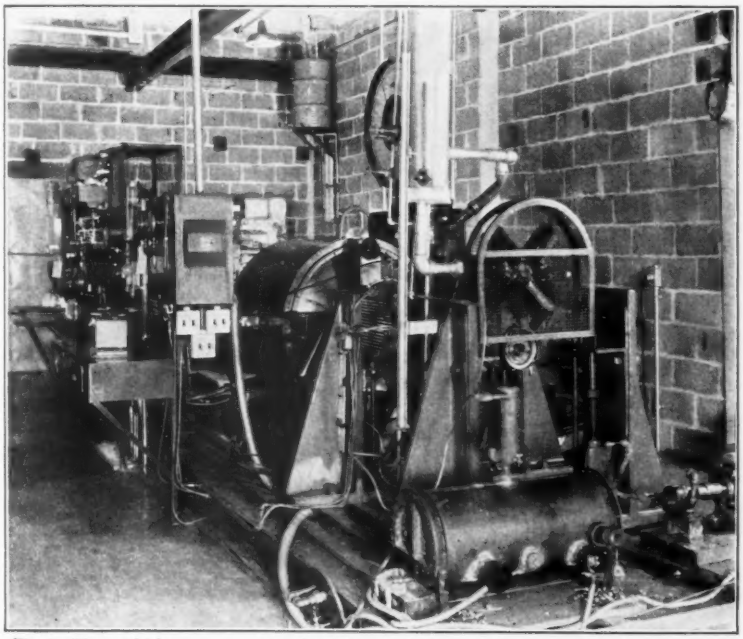


Fig. 2—View of high power output engine-dynamometer set-up using external heat exchangers for maintaining high crankcase temperatures.

MOTOR LUBRICATION

We cannot obtain continued high power output, however, unless lubrication of the internal combustion engine is planned to synchronize with the fuel. In other words, a sluggish starting engine or one which warms up slowly due to inability of its lubricating oil to flow readily at low temperatures will show a material reduction in power output, regardless of the quality of its fuel.

By associating quick starting with lubrication, another interesting field of research was developed, based upon the chassis dynamometer and laboratory cold room. The former had already proved its value from a fuel viewpoint several years before; with the perfection of cold room refrigeration and the construction of new research laboratories by some of the most prominent oil companies and automotive builders one could observe just how a car would behave under controlled cold conditions. This afforded opportunity to study engine starting, crankcase dilution and the relation of the viscosity or relative fluidity of motor oils to their pour test.

AVIATION

The aviation engine received its share of consideration in the petroleum research laboratory when increased speed, efficiency and greater power were demanded with the success of trans-oceanic and trans-continental flying. During the World War, aviation required no special gasoline, for the volatility of the regular grades was adequate for the type of short-hop flying which prevailed. Improved design emphasized the importance of the volatility, anti-knock value and stability of aviation gasolines and the heat-resisting ability of airplane

oils. All this was accentuated by the dependability demanded by the air mail and transport service where engine failure might readily spell a fatal forced landing.

To some extent it was practicable to correlate aviation engine research with the automotive engine. The data developed with regard to the latter, however, could only be a guide; the airplane engine had to be treated as a specialty. So here again the petroleum industry worked with another—the aviation industry—in the test rooms of the engine builders, the maintenance shops of the transport companies and on the flying fields.

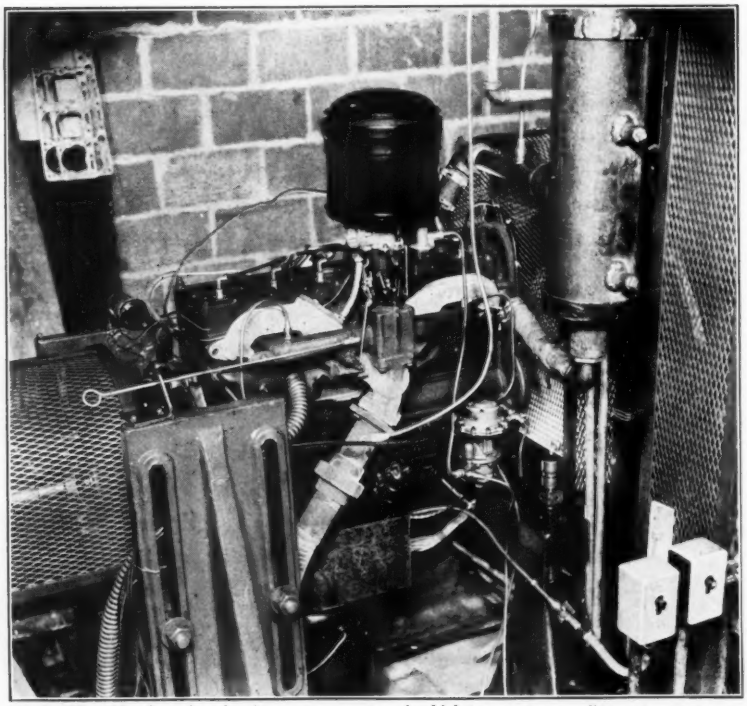


Fig 3.—Top-side view of engine-dynamometer set-up for high temperature cooling system tests.

Engine design requires that the cylinders be kept cool under high load conditions; power requires that harmful detonation be eliminated; dependability calls for protected lubrication. These have guided the petroleum refiner in his research and perfection of the modern 100 octane aviation gasolines and heat-resistant airplane oils.

Lubricating oils for airplane and Diesel engines, as well as for certain types of industrial service, have most recently been studied with regard to their ability to function dependably under the severe operating conditions which prevail in modern service. These oils must also be more stable and less readily affected by heat than ever before. The petroleum industry has learned that the stability of such an oil may depend as much on its operating surroundings as on its internal structure. Metals, as well as oxygen, are important factors in the deterioration of such oils. Copper has long been known to be an objection in this regard. More recently, research has proved that iron in certain forms is likewise a major deterrent to the maintenance of dependable lubrication.

So the oil industry had to study the effect of metals upon an oil film when sliding pressure is applied. It has been developed that an optically smooth steel surface, when protected by an oil film of only a few molecules in thickness, and exposed to the sliding action of a hard smooth stone, can withstand around one hundred thousands per square inch of sliding pressure without tearing. In turn, the research scientist has proved that if the sliding element is a rounded diamond, greater loads can be carried. On the other hand, if the slider is of steel, failure occurs at comparatively low pressures.

It is to increase the load carrying capacity of the oil film, and to postpone failures in certain operating mechanisms, where we must deal with metals only, that additives are included. Some additives by reason of their oiliness or ability to combine with steel, form an auxiliary lubricating film over which the oil molecules can roll. The problem, however, has been to insure that the additives do not form corrosive bodies or other undesirable compounds under extreme heat or cold conditions.

Another type of additive which has been considered is the so-called "detergent." This acts to keep any carbon which may be formed by fuel blowby or lubricating oil breakdown in a dispersed colloidal form which can be drained out at intervals, to prevent stuck rings or valves. These additives do not generally stop carbon formation; they merely keep it from settling temporarily. So it is still necessary to observe regular periods for draining the oils from the crankcase and renewing with fresh lubricant.

INDUSTRIAL LUBRICATION

Increase in the chemical stability of industrial lubricants has been the most significant result

of the coordination of petroleum research with refinery procedure and industrial requirements. It has been applicable to all types of industrial manufacture, but obviously most pronounced in the field of power development since all are dependent upon power for their operation.

In the Turbine

It was a natural consequence, therefore, to study steam turbine oils as they were manufactured during the post-war period. This led to investigation of the possibilities of solvent refining whereby the readily oxidized gum-forming hydrocarbon constituents might be removed.

The petroleum chemist has also learned the value of measuring the chemical stability of lubricating oils in terms of their resistance to oxidation. In this he is able to accelerate operating conditions of pressure, temperature, moisture and air as they may prevail in a steam turbine lubricating system. He attains his objective in an atmosphere of oxygen or by use of a pressure bomb.

The remarkable records which are available in virtually any steam turbine power plant today are a tribute to the ability of the oil refiner to meet the prevailing pressure and temperature conditions. These same types of oils of higher viscosity have more recently been applied to lubrication of the pressure-oiled, sleeve-type, steel mill roll neck bearing with equal success and every indication that like durability will signalize their performance.

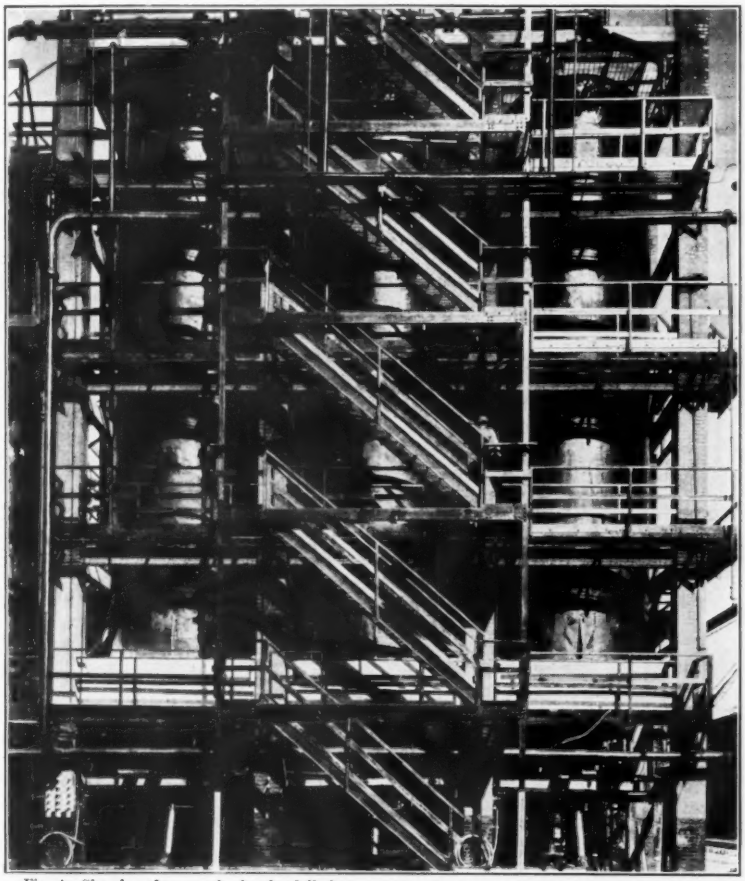


Fig. 4—Showing the magnitude of a full size pressure coke still. Such stills are capable of running a wide variety of charge stocks, ranging from topped crude oils to heavy residual cracked oils, in the ultimate production of gas oil and coke.

Refrigeration and Air Conditioning Compressor Oils

Refrigeration or the production of controlled low temperature conditions has been studied for upward of a hundred years. At first the industry was concerned with augmenting the supply of natural ice; then, with the cooperation of the bacteriologist, food preservation for longer periods of time was studied. Later came electric refrigeration, air conditioning or comfort cooling, quick freezing and locker storage; all a tribute to the ingenuity of the refrigerating engineers, the research chemist and the bacteriologist.

The machinery required for the development and maintenance of refrigeration, in turn, involves the petroleum industry and the lubricating engineer. Lubrication of the refrigerating compressor is of distinct interest due to the fact that one has to consider with equal import the ability of petroleum lubricating oil to protect the moving parts, as well as the effect which might result should this oil pass over with the refrigerant, to perhaps congeal in the low temperature side of the system.

It was essential to consider this latter more seriously than ever when the chlorinated and fluorinated refrigerants were introduced. Mineral or petroleum oils mix or go into complete solution with these chemicals, to result in marked reduction in the viscosity or relative fluidity of the oils. In addition, the petroleum chemist had to realize that he was dealing with a complex mixture which could readily become

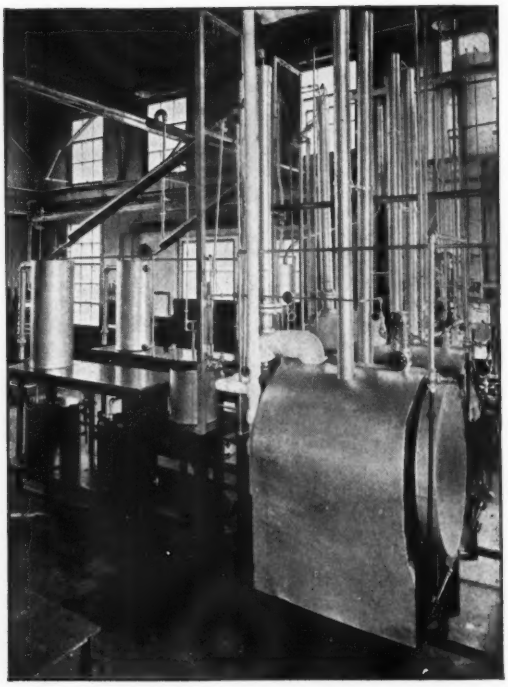
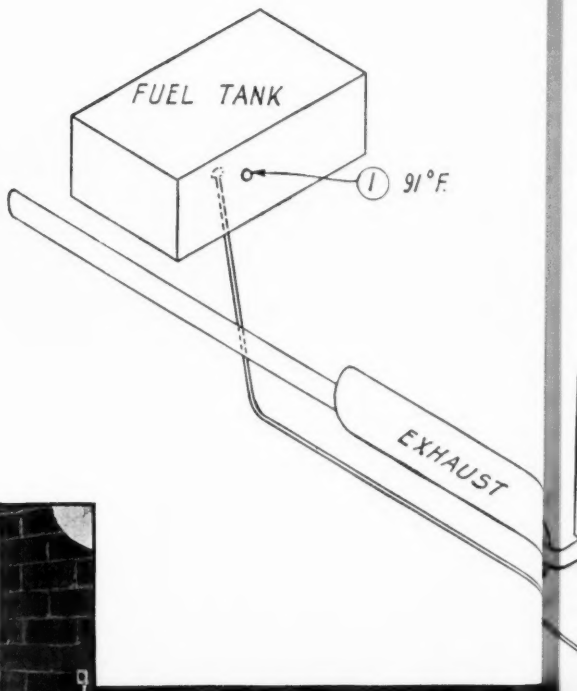


Fig. 5 (Left)—View of experimental steam stills for the study of solvent refining and solvent dewaxing.

Fig. 7 (Below)—Schematic diagram showing pl whi automotive engine fuel system when studying va tem main fuel tank, (2) The fuel pump inlet, (3) The fu out bowl, and (6) The main fuel jet. The temperatur ed after a steady run at 40 m.p.h., on a seven per c



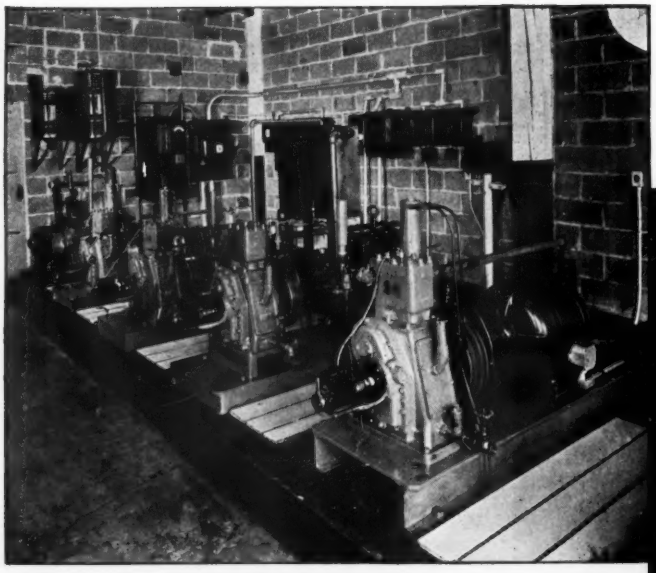
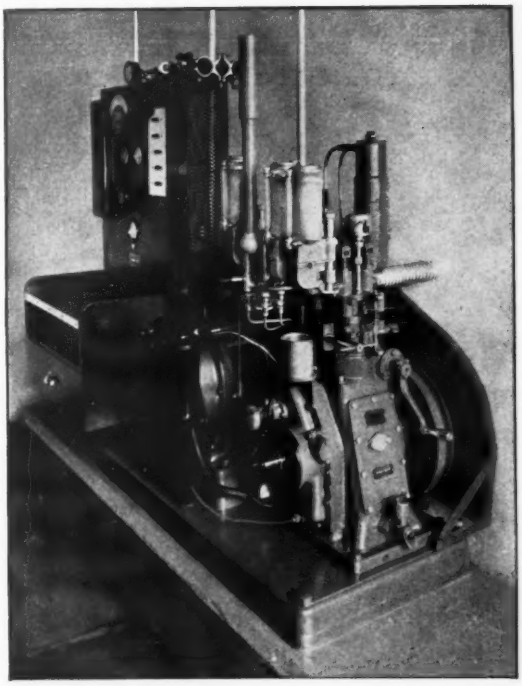


Fig. 6 (Above)—View of battery of engines for testing ring sticking qualities of lubricants.

Fig. 8 (Above)—Laboratory apparatus for studying th tion characteristics of lubricating oils.

Fig. 10 (Right)—Standard C.F.R. Test Engine for determining anti-knock properties of motor fuels.



wing p[illegible]hich temperature measurements are made in an ing va[illegible] tendencies. Note that these are taken at (1) The The fu[illegible]outlet, (4) The carburetor inl[illegible]t, (5) The carburetor erature[illegible]d are for 75 degrees Fahr., air, idling at 360 r.p.m. per cy[illegible]

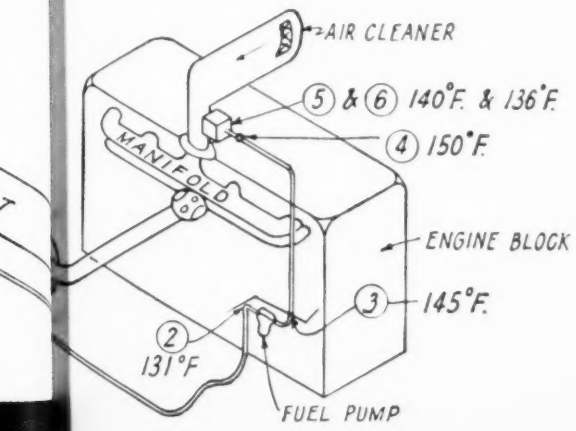
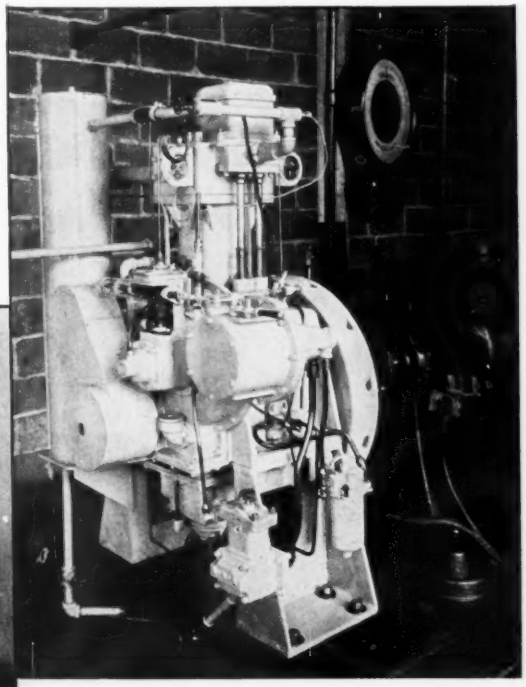


Fig. 11 (Below)—Experimental set-up of single cylinder Caterpillar Diesel Engine used in study of Diesel fuel and lubricant qualities.



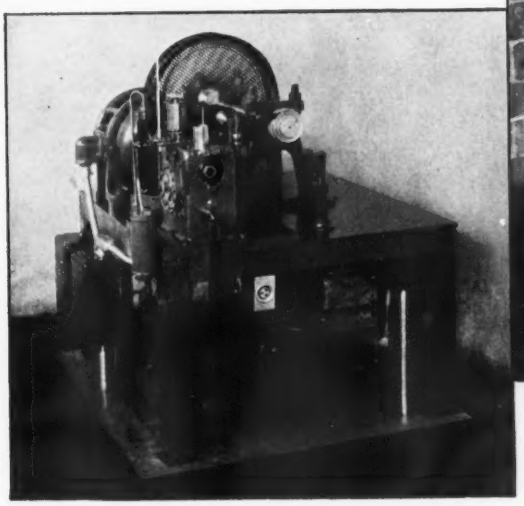


Fig. 9 (Left)—View of Extreme Pressure Tester for determining quality of E. P. Lubricants.

unstable or subject to reaction in the presence of moisture.

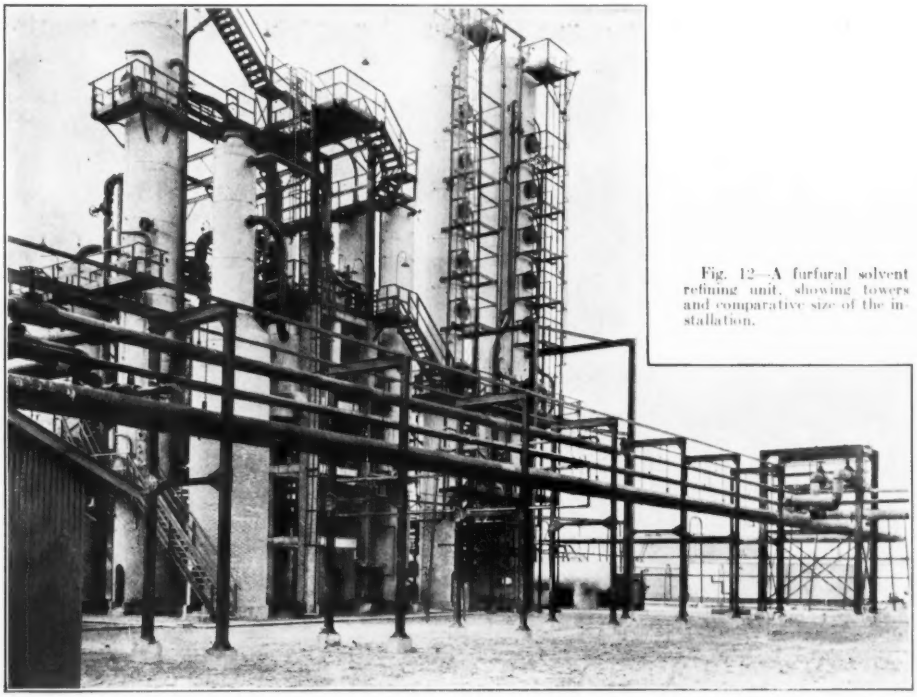


Fig. 12—A furfural solvent refining unit, showing towers and comparative size of the installation.

This called for an intensive campaign of research on the part of refrigerating machinery builders, the chemical industry and the refinery chemist. It imposed a most exacting obligation upon the petroleum industry—to develop a type of lubricating oil which would

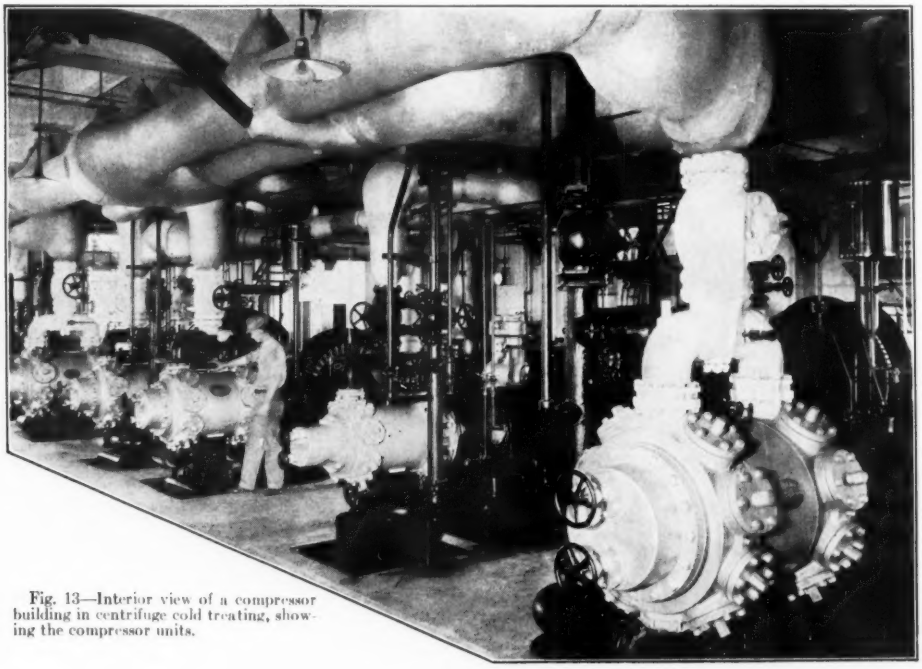


Fig. 13—Interior view of a compressor building in centrifuge cold treating, showing the compressor units.

resist chemical action regardless of the type of refrigerant. Low pour test and high dielectric strength (freedom from moisture) were physical requirements which also were mandatory.

The ensuing research developed a very interesting relationship between the resistance to oxidation (by accelerated test procedure) and the chemical stability under non-oxidizing conditions of operating. It proved the ingenuity of the petroleum research chemist in developing comparative data which becomes most valuable in predicting the operating performance of a lubricating oil.

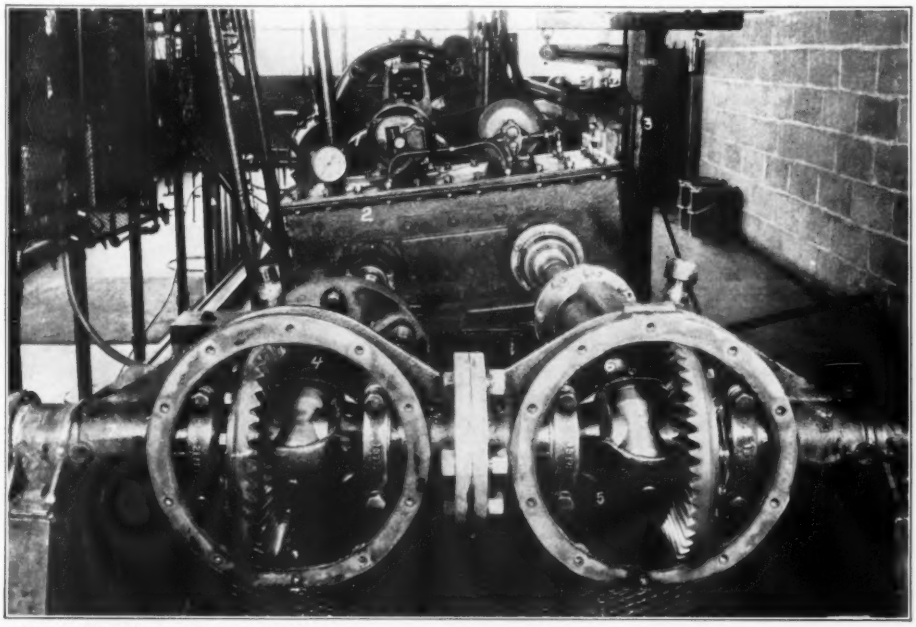


Fig. 14—Hypoid gear test set-up showing:

1. Cradle mounted dynamometer used to drive the system and also to measure the torque input to the system.
2. Transmission box containing four herringbone gears, one of which is on each of the two shafts, the other two gears being idlers between the two shafts.
3. Platform scale used to measure torque load applied to the hypoid gears. The transmission is hung or pivoted about the shaft immediately under the No. 2. Raising the box about this shaft applies a load to the system, which is measured by the reaction of the box against the platform scale.
4. Differential carrier—from which differential gears have been removed and replaced with a shaft which connects the two ring gears.
5. Same as No. 4. 6. Pinion Gear. 7. Axle housing.

SOLVENT REFINING

Solvent refining gave the refiner a valuable tool in his job of refining a given lubricating oil stock to meet these specifications and still avoid the dangers of over-refining. By this means he is able to make a better separation of objectionable constituents and obtain a higher quality oil from a given crude source.

Briefly, solvent refining consists of contacting the oil to be refined with a solvent which possesses the property of being able to dissolve out undesirable unsaturated hydrocarbons and at the same time is inert to desirable constituents such as paraffines and saturated naphthenes. The process is purely a physical separation and no chemical reaction occurs.

The oil to be refined is contacted with the solvent in counterflow operation either in a packed tower or a step counterflow system consisting of alternate mechanical mixers and settlers. The unsaturated hydrocarbons go into solution in the solvent while the saturated hydrocarbons remain out of solution. This results in a two-phase system consisting of refined oil as one phase and solvent plus dissolved unsaturated hydrocarbons as the other phase. The solvent has a much higher specific gravity than the oil so that the two phases are readily separated by gravity settling. The solvent is recovered by distillation and recirculated through the system.

Several solvents have been developed for refining purposes, such as sulfur dioxide, furfural, phenol and chlorex. Although any one of these solvents may be used, they do not all remove the same type of compounds to the same degree, and the refiner must adjust his subsequent processing accordingly.

Where more than one solvent treating system is available, the refiner chooses that system

which is most suitable to the results he desires. If only one system is available he must adjust his subsequent treatment accordingly.

The refining yield that is obtained depends upon the desired quality of the refined oil and the quality of the charge stock. It is varied by changing the treating temperatures and ratio of solvent to oil used. The undesirable constituents removed by solvent refining are discarded as far as use in lubricating oil manufacture is concerned.

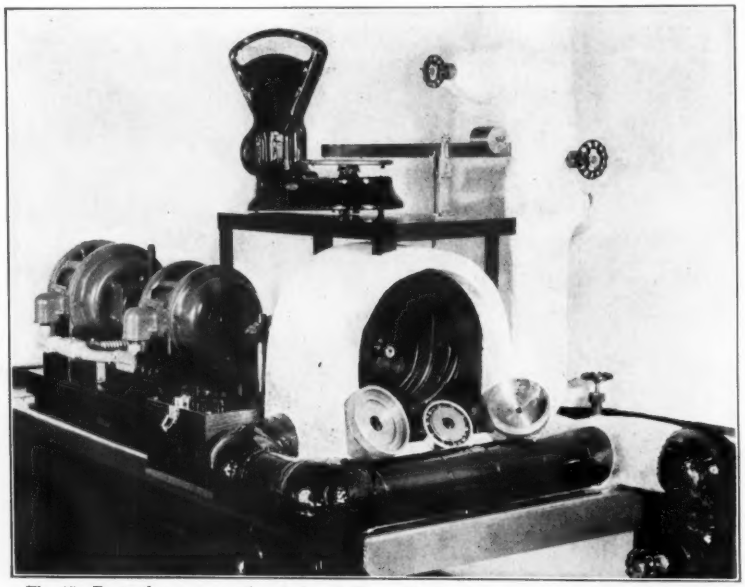


Fig. 15—By testing a grease directly in a ball or roller bearing under controlled operating conditions, most interesting data can be developed in the prediction of its durability. The above is a two-speed torque-breakdown machine equipped for steam heating or refrigeration, with means for torque measurement.

Solvent refining systems, however, may not completely remove all of the unsaturated hydrocarbons that it is necessary to remove in order to produce a lubricating oil having the high degree of stability that is required in an oil to be used in turbine service or a sealed refrigerating unit. Nor is any one refining system one hundred per cent efficient. It is, therefore, often necessary to use additional treating processes to insure a quality oil.

Acid treatment of the oil is one of the most common methods used to give further refinement. Acid treatment differs from solvent refining in that the sulfuric acid used reacts chemically with the unsaturated hydrocarbons, whereas solvent refining gives purely physical separation.

Sulfuric acid treatment when used is chiefly a batch operation, although continuous equipment involving the use of centrifuges for continuous removal of the acid sludge has been developed and is used in many refineries. The oil is pumped to a large lead-lined treating tank and thoroughly mixed by air agitation with from twenty-five to one hundred pounds of 98 per cent sulfuric acid per barrel of oil, depending upon the viscosity of the oil and the degree of refining desired. During agitation the sulfuric acid reacts with the unsaturated hydrocarbons to form a heavy tarry mass that is removed by quiescent settling. The acid sludge that is removed is mixed with water to remove unreacted acid, and then burned as fuel.

After removal of the sludge it is necessary to insure complete removal of the sulfuric acid from the treated oil. The acid oil is usually agitated with water to remove the bulk of the free acid. After drawing off the acid water, the remaining traces of acid are removed by neutralizing the oil with a caustic soda or soda ash solution. The neutralized oil is then steamed to remove soaps that are formed by the neutralization. After steaming, the oil is blown bright with air to remove excess moisture.

Considerable prejudice, abetted by propaganda, exists among laymen unfamiliar with the refining of lubricating oils against the use of an oil that has been refined with sulfuric acid. This is apparently due to a feeling that there is some danger that all of the sulfuric acid will not be removed and that if any traces of acid are left it will result in metallic corrosion. It can not be too strongly emphasized that every precaution is taken to insure complete removal of even minute traces of mineral acids. This prejudice may also be due to a misunderstanding of the meaning of the term "Neutralization Number" as applied to a lubricating oil. Lubricating oil specifications usually show a maximum permissible Neutralization Number. This does not mean that the oil may contain any traces of mineral acidity. Practically all oils, regardless of how extensively or carefully refined, contain traces of organic acids which are not necessarily corrosive and which should not be confused with mineral acids. The Neutralization Number specification applies only to organic acids.

After the high degree of refining that is obtained by combined solvent refining and acid treatment, the resulting oil is highly satisfactory for many types of automotive and indus-

trial lubrication, yet it is still not considered to be sufficiently refined for use in refrigeration equipment. The refined oil may still contain small traces of high molecular weight color bodies that if allowed to remain in the oil might oxidize to form small quantities of sludge that would plug delicate expansion valves or lower heat transfer in the evaporators. The oil may also contain small quantities of oil soluble soaps formed by the reaction of neutralizing caustic with organic acids.

The above impurities are removed by percolating the oil through a bed of fullers earth. Fullers earth is a natural adsorptive clay that has the property of being able to adsorb coloring bodies and small traces of soaps from an oil. The oil is slowly pumped through the clay bed at relatively low temperatures of the order of 100 to 150 degrees Fahr., depending upon the viscosity of the oil. The volume of oil per ton of clay depends upon the degree of refinement desired and roughly varies from twenty-five barrels of oil per ton of clay to about one hundred barrels per ton of clay.

GREASE RESEARCH

The petroleum industry came to appreciate the necessity for high stability lubricating greases with the perfection of the anti-friction bearing. Considerable plant study had been given to grease manufacture for years, but when the builders of the ball and roller bearing designed for prolonged periods of operation on but a few ounces of grease per bearing, the petroleum industry was obligated to protect these mechanisms with greases of quality equal to the quality of the engineering and materials put into the bearings.

Iron and steel and the railroads became enthusiastic proponents of the heavy duty roller bearing; the textile, motor and machine tool builders adopting the ball bearing; the automotive and aviation industries use both types. All presented operating conditions which encouraged breakdown of ordinary greases. Adverse pressure, temperature and water conditions surround the heavy duty bearing, while high speed, dust, mill dirt and widely varying operating temperatures often may affect electric motor, machine tool and textile mill bearing performance.

So the bearing manufacturers have sealed their bearings against entry of contaminants wherever possible, and the petroleum industry has established the art of grease manufacture as a major research problem.

The progress in this field has been most interesting; it has entirely justified an expenditure of millions of dollars in the training of research personnel, the perfection of unique laboratory equipment and the most accurate standardization of refinery procedure.

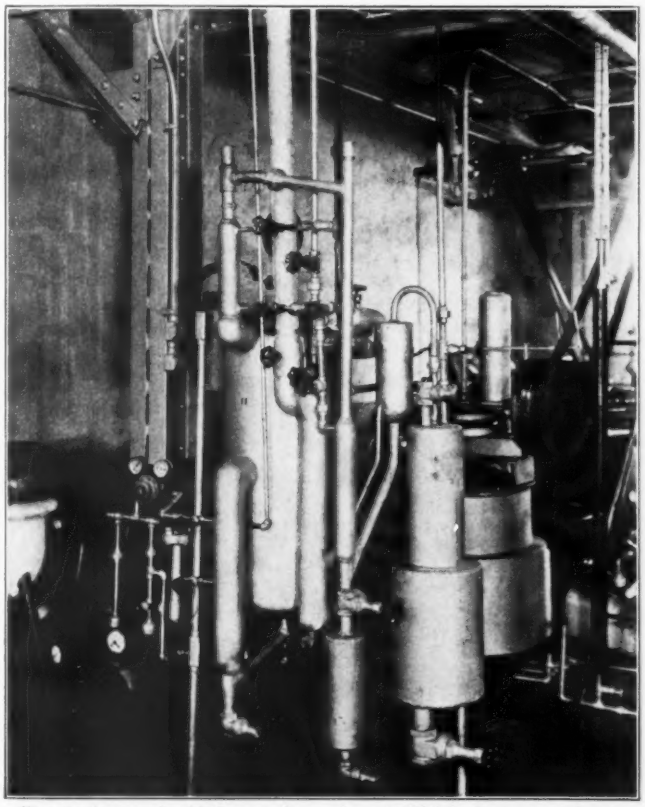


Fig. 16—A type of oxidation reaction equipment which is also necessary in grease manufacture and evaluation.

The lubricating value of a grease is contingent upon the materials from which it is manufactured. Essentially these include petroleum lubricating oils and soaps prepared from saponifiable fats. All must be of high quality and resistant to chemical breakdown; otherwise, the grease will oxidize in service or storage to a resinous or gummy state which will prevent free movement of the bearing elements, and probably cause more or less corrosion.

The basis of modern grease research is to prevent the above. Success is denoted by the fact that industry as a whole today uses upward of two hundred millions of pounds of grease annually at an estimated value of twenty million dollars to the petroleum industry.

Resistance to Flow

There is, of course, a direct relation between the rate of change in physical characteristics of a grease with temperature or pressure, and its performance in service. Change in consistency which would be comparable with change in viscosity in an oil has prompted a number of investigators to attempt to develop a method of determining the viscosity of greases or their resistance to flow, as a guide to prediction of the temperature range over which any such product should be used, and the relation of torque, or power consumption, through internal friction.

Any device for determination of change in consistency or viscosity with pressure or temperature involves a static test. In realization of this fact, there has been an interesting trend toward development of a testing machine which will enable visual observation of the behavior of a grease under actual service conditions. Details of two of such machines for the study of breakdown tendency and torque, or power consumption, in grease-lubricated ball or roller bearings are shown in Figures 15 and 17. These machines enable such observations to be obtained simultaneously with suitable data for plotting of torque curves for any comparatively plastic grease, in terms of gramcentimeters. These data are obtainable under service temperature conditions.

Actual service tests on greases especially devised for ball and roller bearing lubrication have shown a most interesting agreement with the data and observations made on the same products on the Torque-Breakdown Machine. They have proved conclusively the value of correlating laboratory research with practical service in the study of refinery practices incident to manufacture of specialty greases and other lubricants designed for intensive duty.

In the study of torque characteristics of various types of grease, the data developed indicates that while the consistency may control the initial torque, after a condition of equilibrium is approached, the viscosity of the oil becomes more of a controlling factor. Research has also proved that torque is materially affected by the method of manufacture.

SUMMARY

It has been a fascinating duty to thus review the factors which have distinguished the petroleum industry for its appreciation of cooperative research. It is fondly hoped that our contributions to science and to machine design may have an ever-increasing benefit to those who have to make machinery run under what may not always be the most ideal conditions. A whole-hearted effort will be directed in a continued endeavor to simulate these conditions in the laboratory in order that petroleum products may be as dependable and efficient as science will permit.

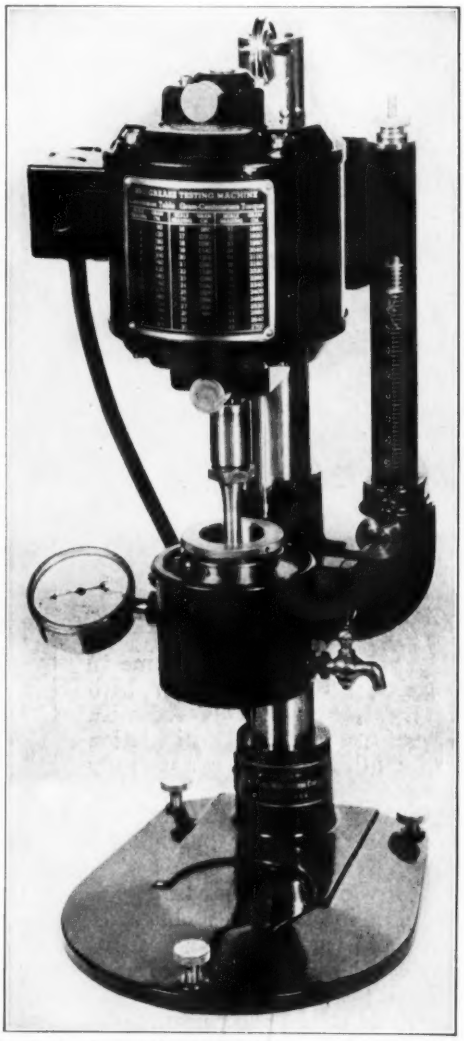


Fig. 17—Another machine developed for grease testing by the Annular Bearing Engineers Committee. This device is helpful in evaluating ball bearing greases, studying leakage tendencies and torque characteristics.

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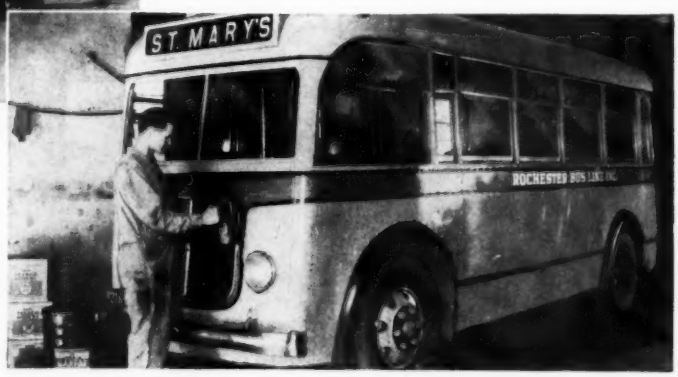

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